Long Term Performance of the Pressure Swing Recirculation System

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ABSTRACT:

Proton Exchange Membrane Fuel Cells are electrical generators that use oxygen and hydrogen to produce electricity. To minimize the wastage of hydrogen, recirculation systems are used to prevent the flooding of the fuel cell and to limit the reactant losses. Those systems impact the efficiency of the fuel cell due to their electrical consumption. A new system of hydrogen recirculation is presented using the hydrogen consumption as the driving force of the system instead of a pump. This recirculation device was successfully tested on a 70 cells 7 kW stack. During this test, the fuel cell system works for 6h45 with only a decrease of performances of 2%. The overall gain in system efficiency was 2%.

KEYWORDS: hydrogen recirculation, suction pressure, fuel cell, reactant losses

Introduction

PEMFC are electrochemical device that convert chemical energy in electricity by using the reaction between hydrogen and oxygen. PEMFC are more and more considered for various applications due to their quick start capacity, environment friendly aspect and low operating temperature.

PEMFC are name after their electrolyte, the Proton Exchange Membrane. They use the chemical reaction between H_2 and O_2 usually from the air to create electricity. The hydrogen is oxidized on the anode; the electrons are injected in the eternal electrical circuit; the ions go through the membrane. Then both of them react with the oxygen to create water and heat. The membrane needs to be hydrated to ensure a good ionic conductivity. The hydration is done by a hydration of the reactant or/and by the impregnation of the membrane by the water created by the chemical reaction. This impregnation is made possible by the porosity of the membrane and by the difference of concentration of water between the anode and the cathode. So there is water on both side of the membrane. Due to operating temperature and pressure, the water is liquid and can cover the active area and prevent the electrochemical reaction to occurs [1]. This water need to be evacuated to ensure a good functioning of the fuel cell. Also, due to the porosity of the membrane, some of the nitrogen present in the air in the cathodic compartment can go through the membrane to accumulate in the anodic compartment. This nitrogen also impacts the performances of the fuel cell [2].

For the rest of the paper, we are going to discuss anodic compartment issues and means to deal with it. The reactant supply system needs to have a pressure regulator to control the pressure in the anodic compartment. Several modes of functioning are used to deal with the water and the nitrogen. The Dead End mode blocks the outlet of the anode. The anode is supplied by the pressure regulator and no reactant is lost. This solution is simple but allows the accumulation of water and inert substance in the anodic compartment and then a loss of performances [3]. Another solution is to use a purge mode. It’s a cyclic mode. During the first part of the cycle, the fuel cell works in dead end mode. During the second part of the cycle, the outlet of the fuel cell is opened and the water and the inert substance are purged from the fuel cell. This system is simple and only need a solenoid valve to work. This solution has an impact on the efficiency of the fuel cell because during the purge some reactant is lost. The purge system is currently used for operative fuel cell[4].

Most of the high power fuel cells use a reactant recirculation loop, usually powered by a pump [5]. The reactant supply system is modified to integrate a pump, a 3-way tube and a water purge. The hydrogen comes in the circuit, then goes through the 3-way tube to the stack, and then into the water purge. Then the gas is pushed by the pump to the 3-way tube to re-enter the stack. The water trap catches the water created in the fuel cell. The important flow created by the pump pushes out the excess water from the stack and homogenizes the nitrogen and hydrogen mixture. This solution is simple. The problem of the pump is the extra energy cost due to the power supply of the pump. This is a good way to deal with the water but that does not prevent nitrogen accumulation i.e. the loss of performances. Innovating methods are also used like the electrochemical pump of hydrogen but the problem of the inert gas and water accumulation remains with that solution.

We propose another solution to prevent those issues. We present an innovative reactant recirculation system without a pump. This system was tested for a single cell. We propose to study it to 70 cell stack. For the rest of this paper, we will call this system "Pressure swing recirculation system", PSR system.
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Pressure swing recirculation system
Principle

This pressure swing recirculation system evacuates the water from the fuel cell without using a pump. The driving force of this device is the hydrogen consumption during the fuel cell operation.

Design

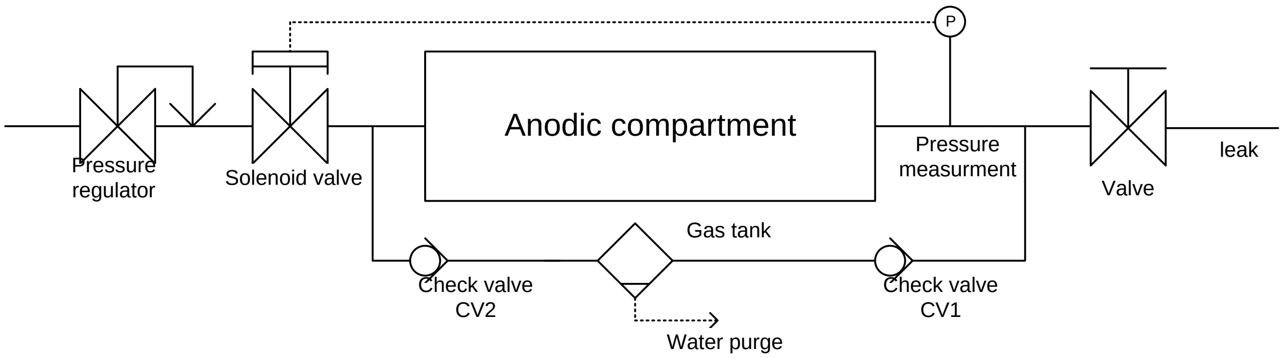

Fig1 : Schematic diagram of the pressure swing recirculation system.

Only the anodic side of the fuel cell is shown. This device is composed of several elements: a pressure regulator, the anodic compartment where the hydrogen consumption occurs, a gas tank, also used as a water trap, 2 check valves and a solenoid valve commanded by a pressure measurement on the anodic compartment. The next section will explain the driving force of the device.

Driving force of the system

PEM Fuel cells use the chemical reaction between H_2 and O_2, often from air, to generate electricity. The hydrogen is oxidized on the anode; the electrons are injected in an external electrical circuit whereas the ions go through the membrane. Then both of them react with oxygen on the cathode to create water and heat. The hydrogen consumption in the anodic compartment creates a pressure drop which is used as the driving force of the pressure swing recirculation system. The following section will explain the functioning of the pressure swing recirculation device.

Functioning principle

The functioning of this system is based on a four steps cycle.

The next paragraph will explain the functioning of the pressure swing recirculation. The next figure presents the evolution of pressure in both the gas tank and the anodic compartment during the functioning.

1. The solenoid valve and the two check valves being closed; the hydrogen is consumed by the fuel cell. The pressure thus decreases in the anodic compartment of the stack.
2. The pressure decrease causes the opening of the check valve CV2. This leads to a discharge of the gas from the tank to the stack due to the pressure difference (higher pressure in the tank).The pressure in the anodic compartment and the stack still decrease due to the continued consumption of hydrogen.
3. When the pressure reaches the low pressure limit, the solenoid valve opens. The pressure rises in the anodic compartment leading to the shutdown of the check valve CV2.
4. The difference of pressure between the anodic compartment and the tank causes the opening of the

check valve CV1 (higher pressure in the anodic compartment). Then the anodic compartment discharges itself in the tank creating an overflow through the anodic compartment which expels water and inert gas out of the stack.

When the anodic compartment pressure reaches the high pressure limit, the solenoid valve closes along with CV1. The cycle can start again.

The following figure presents the pressure variation in the anodic compartment and the gas tank.

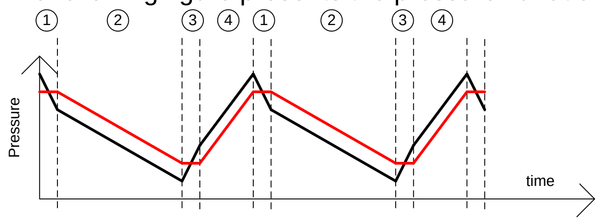

Fig2 : Evolution of pressure in the anodic compartment (black) and the gas tank (red)

This system was already tested on a single cell [6]. We also test this system on a 70 cell 7kWe stack. We show that this system is able to deal with water but that as expected the nitrogen accumulation is an issue [7].

Nitrogen accumulation

In a recirculation loop, N_2 can be accumulated in the anodic compartment. Some nitrogen crosses the membrane to the anodic compartment. This crossing is induced by the part pressure gradient between the cathodic and the anodic side. After a long time of functioning, the part pressure of nitrogen in the anodic compartment becomes equal to the one on the cathodic side. The rate of this crossing depends on the volume of the hydrogen recirculation loop and on the characteristic of the membrane [8]. The nitrogen impacts the efficiency of the fuel cell. But with an effective recirculation loop, the anodic gas can be homogenized to avoid nitrogen plug. Some paper report a well functioning fuel cell with a ratio of 80% of nitrogen in the anode[9]. But in other case, nitrogen has a negative impact on the fuel cell performances [2].
The solution is to allow a leak to prevent nitrogen accumulation. This will limit the accumulation of nitrogen in the fuel cell.

Experiments

A 70 cells fuel cell with an active area of 200 cm² using hydrogen and air as reactant is used in the experiment. The membrane electrode assembly (MEA) is constituted of Nafion, Pt/C electrodes with a Pt catalyst loading of 0.1 mg/cm² on the anode and 0.4 mg/cm² on the cathode, and GDLs (24 BC). The pressure of air in the cathodic compartment is 1500 hPa(abs). The temperature of the fuel cell is 70°C. The air stoichiometry is set to λ_c=2.5. This system is made of two check valves with a pressure crack of 0.03 hPa. A solenoid valve was added to the hydrogen line. The volume of the gas tank and the pipes between the two check valves is 4 l. The water trap is made up of a condenser and a bucket trap. The constant leak is set to have an external stoechiometry of 1.007.

Results

The following figure presents the evolution of the mean voltage of the cells of the fuel cell during the 6h30 long test for a current density of 0.5A/cm² and the nitrogen ratio in the anodic compartment.

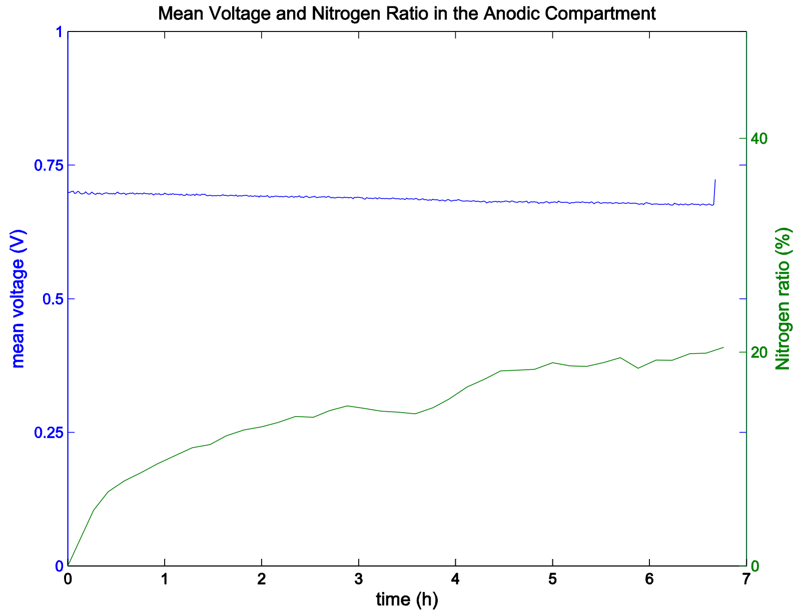

Fig : Mean Voltage and Nitrogen accumulation during a 6h45 long test of the PSR system at 0.5 A/cm²

With this configuration, the performances were sustained for 6h45 with a little reduction on the efficiency of the fuel cell of only 2%. This loss is due the nitrogen accumulation that is limited to 20% thanks to the leak. The nitrogen ratio being stable after 6h, the experiment was stopped. During this test the overall gain in system efficiency was 2% compared to the original system equipped of pump recirculation system.

Conclusion

Pressure swing recirculation system already show is capability to deal with water in the anodic compartment. We show that adding a leak to the system allow to prevent the nitrogen accumulation and therefore allow a long run of the system. The Pressure Swing Recirculation System still better in term of efficiency that over hydrogen recirculation device even with the leak.

Acknowledgment

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